FINAL REPORT

Influence of fire severity and canopy cover on the population dynamics and harvest quality of beargrass (*Xerophyllum tenax* Melanthiaceae) in the Cascade Mountains of Oregon

JFSP PROJECT ID: 15-2-01-16

DECEMBER 2017

Georgia Fredeluces, M.S.
Department of Botany, University of Hawai‘i at Mānoa

Tamara Ticktin, Ph.D.
Department of Botany, University of Hawai‘i at Mānoa

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List of Abbreviations/Acronyms

ANOVA – analysis of variance
dNBR - differenced Normalized Burn Ratio
GLM – general linear mixed model
GLMM – generalized linear mixed model
IPM – Integral Projection Model
LMA – leaf mass per area (grams/m^2)
LTRE – life table response experiment
m – meter
mm - millimeter
NTFP – non-Timber Forest Product
SLA – specific leaf area
Tukey HSD – Tukey honest significant difference test
USFS – United States Forest Service
VWR – a brand name that makes drying ovens

Keywords

population biology, beargrass, ethnobotany, forest ecology, harvest, fire severity, American Indians, canopy cover, soil moisture, fire effects, understory, Oregon, subalpine, climate change, management, demography

Acknowledgements

I would like to thank the Joint Fire Sciences Program for supporting this work through the Graduate Research Innovation Award, which funded the major component of my dissertation research costs. As a student, I have also been supported by a Graduate Research Assistantship through Pacific Cooperative Studies Unit under Dr. David Duffy. My dissertation would not have been possible without each of these sources of funding. I also thank the Beatrice Krauss Fellowship Fund, the Winona Piʻilani Char Scholarship and the Torrey-Degener-Rock Scholarship Endowed Fund, all offered through the Department of Botany at the University of Hawaiʻi at Mānoa, for research funding. Demographic data is time-intensive to collect and required multiple field assistants as well as long-distance travel. I thank the Department of Botany at the University of Hawaiʻi at Mānoa for supporting me as a graduate student. I would like to thank my adviser, Dr. Tamara Ticktin for sharing her expertise, support, guidance and positive, appropriate encouragement throughout the many and various research challenges. Big thanks to my committee members, Dr. Orou Gaoue (University of Tennessee), Dr. David Duffy (University of Hawaiʻi), Dr. Mehana Vaughan (University of Hawaiʻi), Dr. Heather McMillen (USFS), Dr. Frank Lake (USFS), and Dr. Creighton Litton (University of Hawaiʻi). Thank you to Dr. Susan Hummel (USFS) for support, guidance and lending field equipment as well as making a trip to the field with me. Thank you to Amber Sprinkle (USFS Special Products) for taking me to possible study sites and processing my research permits, and to Todd Reinwald (USFS) for soil identification. Thank you to Ed Geuerrent at the Rae Selling Berry Seed Bank & Plant Conservation Program for allowing me to run germination trials at the lab, as well as the Oregon State Seed Lab. Thank you to Dr. Beverly Law and students for allowing me to visit and utilize lab equipment for LMA and allometry measurements. I would like to thank Rose High Bear, Louise Wilmes, Ciarra Greene, Daniel Dixon, Amanda Kelley-Lopez, as well as others at the Wisdom of the Elders, Inc. for the learning opportunities and friendship that helped guide my process as a Ph.D. student and more broadly in life. Many thanks to the Ticktin Lab members for advice, presentation feedback, and more. Thank you to E. Housley, Isaac Hart, Hiram Hart, and Nancy Hart for technical support and for providing me low-cost or free housing during fieldwork. Thank you to my field assistants Vicki Marsh, Lobo White, Megan O'Driscoll, Alex Harwell, Ashley Blazina, Caitlin Kuehl, Rosebud and Annie Whipple, Matthew Corley, Sandra Amiry and Jeremiah Graff. Thank you to Pah-tu Pitt for facilitating my relationship-building and learning process during this project. Thank you to the basket weavers Elaine St. Marten, Barbara Krommer, Jo Ann and George Hart, Robert Kentta and others who shared with me their time, knowledge, patience and in some cases also spent significant time with me and my husband, teaching us weaving techniques. Huge thanks to my mother Siri Jackman for supporting me tirelessly in tedious fieldwork for which I did not have money to hire assistants. Finally, I want to warmly thank my husband Gilbert Fredeluces for being with me through the completion of the Ph.D., supporting me and working full-time, unpaid, as a field assistant for the entire 2017 field season in less-than-comfortable conditions. I think it would be fair to take my Ph.D. diploma (when acquired) and tear the paper into three parts: one I would keep for myself and each of the other two pieces would be given to my mother and my husband. Many probably share my experience that being a graduate student at a public university requires living with a lot of uncertainty, including uncertainty about when and how financial resources can be acquired to get the work done. I wish it could have been easier, but these individuals and funding sources mentioned here are what helped ease my burden. Mahalo nui loa and thank you all.

Abstract

The U.S. Forest Service multiple-use concept establishes the importance of managing forests for diverse stakeholders and values. The availability and quality of culturally and economically significant plants are part of this mandate. Beargrass (*Xerophyllum tenax* Melanthiaceae) is a fire-adapted, perennial evergreen herb found in the Pacific Northwest that is ecologically important for animals from insects to grizzly bears, economically important for commercial harvest by the floral industry, as well as culturally important in indigenous basketry. Beargrass provides a white overlay, weft or other function for Native American weavers across the Pacific Northwest where basketry forms a cornerstone of cultural identity. While the size and abundance of plants may be important for all harvesters, indigenous weavers have specific quality standards for harvestable leaves that may include the color, length, strength, and pliability. These plant qualities are achieved through Indigenous Management Systems that include fire. Native Americans have managed beargrass using fire for millennia, and fire is generally considered to increase the quantity and quality of beargrass leaves for basketry. The best quality beargrass is collected 1-3 years after low or moderate intensity fire and in partial shade environments. Fire suppression over the last 150 years has increased fuel loads and reduced the abundance and harvest quality of beargrass such that today it is often difficult to obtain. Investigating the population and leaf trait impacts of contemporary fire regimes and traditional fire management of beargrass can help to improve the availability and harvest quality of this species. Further, learning about Native American management systems for culturally significant plants may reveal new approaches that complement and enhance current practices. For example, research suggests that indigenous management practices for beargrass in the Pacific Northwest aim to create similar forest conditions to those that U.S. government managers strive to produce in order to reduce fire risk. This suggests that indigenous knowledge may offer alternative and complementary management approaches that reduce fire risk while also increasing the abundance and/or quality of plants of cultural value. Fire, canopy cover, and other factors have received moderate research attention for their impacts on plant population dynamics, which are often non-additive and non-intuitive. The influence of these factors on plant *quality* has been much less explored. In this study, in order to assess the impact of contemporary management practices on culturally-significant forest plants, we measured the impact of **fire severity** (a component of fire suppression), **harvest** (according to indigenous practice), **canopy cover** (a component of timber thinning or harvest)**, soil moisture** (a component of climate change) on the population viability (the ability of the population to sustain itself over time) and leaf quality (acceptability to harvesters) of beargrass in the Cascade Mountains of Oregon. This species and these drivers and response variables were chosen as a sample system that emphasizes key management practices and focuses on a plant of high cultural value. In order to accomplish these goals, we established nine plots across three sites in the subalpine areas of the Mount Hood National Forest in north central Oregon. We made an annual census over three years of over 1,000 tagged plants, measuring growth, survival and reproduction. In the second year of the study, we also conducted a harvest experiment. A subset of harvested leaves was measured for their leaf traits that may be important to indigenous weavers including length, width, taper, LMA (a proxy for strength) and color. We found that multiple and interactive drivers influenced beargrass plant demographic processes and that these effects varied with time since fire. In the presence of fire, most demographic processes (the components of the plant life cycle) were stimulated. Plants that experiences low-severity fire generally had the highest plant population

growth rates. Indigenous harvest, increased light availability and increased soil moisture all had a positive impact on long-term population growth rate. Low-severity fire, high severity fire, timber thinning and indigenous harvest of beargrass can all be expected to increase the long-term population growth rate of beargrass in subalpine areas of the central Cascades. Reductions in soil moisture with climate change can be expected to decrease beargrass long-term population growth rates. Measured leaf qualities were influenced by both fire and light availability, in some cases with results different than those published for other studies. Leaf quality preferences vary by weaving style, tribal affiliation, personal preference and other factors. The best way to support Native Americans access to beargrass plants of high quality may be to support and facilitate the care-taking rights and relationships of Tribal Nations to places where beargrass occurs, and to support the co-management or tribal management of portions of public lands.

Objectives

The objectives of the study are to: 1.) examine the plant and population-level consequences of fire suppression (through fire severity), harvest, soil moisture (as a component of climate change) and light availability (a component of timber thinning and timber harvest), as well as their interactions, on beargrass, 2.) to identify the influence of the above drivers on leaf qualities (traits) that may be important to Native American weavers, and 3.) make management recommendations in light of potential trade-offs between population growth rate and leaf qualities across environmental and management conditions.

Background

Non-timber forest products (NTFPs) provide economic, cultural and nutritional value to multiple stakeholders including commercial harvesters, local, and Indigenous Peoples (Ticktin 2004). Understanding the response of these culturally significant plants to fire, thinning and other public land management practices is necessary in order to create inclusive management plans that are in line with the forest multiple-use concept. Over the past few centuries, fire suppression has reduced the availability of some plants used by Native and non-Native people for food, medicine and technology (Anderson 2005). Investigating Native American management for these plants may reveal new approaches that complement and enhance current practice (Boyd 1999). For example, recent research suggests that indigenous management for beargrass (*Xerophyllum tenax* Pursh (Nutt.) Melanthiaceae) in the Pacific Northwest aims to create similar forest conditions to those that government managers strive for to reduce fire risk (Hummel & Lake 2015). This suggests that indigenous knowledge may offer alternative and complimentary management approaches that reduce fire risk while also increasing the abundance and/or quality of plants of cultural value. The investigation and implementation of these alternative approaches would also engage a greater diversity of stakeholders in the management process on public lands.

Fire is a centrally important disturbance in forested ecosystems (Agee 1993), and understanding the impact of fire and other management practices such as thinning and harvest on the population dynamics of NTFPs is necessary to ensure sustainable use and population persistence. In some cases, the interactions of disturbances experienced by these plants are non-additive and non-intuitive. For example, the negative impacts of harvest on the mountain date palm are reduced, not enhanced, when they co-occur with the additional disturbance of fire (Mandle & Ticktin 2012). In addition to understanding the impacts of management practices and their interactions on plant population viability, there is also need to determine effects of management on plant *quality* (Hummel, Foltz-Jordan & Polasky 2012). Beargrass is an NTFP used in basketry and floral arrangements that is understudied in terms of the impacts of fire and light conditions on population dynamics (Hummel *et al.* 2012). Given that harvesters have specific quality standards for usable plants, it also offers a unique opportunity to investigate how management may influence plant quality.

Beargrass is a fire-adapted, perennial evergreen herb with leaves that form dense clumps or tussocks (Hummel *et al.* 2012). It occurs in mountainous regions of the Pacific Northwest, especially in cooler, drier sub-alpine mixed coniferous forests (Crane 1990). Beargrass reproduces both asexually through rhizomes and sexually through seeds, with mass flowering occurring intermittently, at intervals potentially as long as 5-7 years (Crane 1990). Beargrass serves multiple ecosystem functions including providing food, shelter and materials for diverse animals such as insects, elk, and grizzly bears (Crane 1990). From a cultural perspective, it is essential for Native American basketry, providing a white overlay or weft for weavers across the Pacific Northwest where basketry forms a cornerstone of cultural identity (Anderson 2005; Lake 2007; Hummel *et al.* 2012). It is also used for Native American regalia and for other purposes. In addition to Indigenous harvest, commercial harvest of beargrass leaves for the floral industry has been increasing in some regions—nearly one million pounds per fiscal year were harvested by permit on the Mt Hood Forest in 2013 and 2014 (Amber Sprinkle, pers comm.). While the size and abundance of plants may be important for all harvesters, indigenous weavers have highly specific quality standards for harvestable leaves that include color, strength, pliability, leaf size and storage capacity (Hummel & Lake 2015).

The definition of harvestable material depends upon the harvester and the intended use of the beargrass. Indigenous basket weavers show varying preferences for beargrass depending on the weaving style, tribal traditions, and individual preference (Hummel and Lake 2015). In one study, preferred beargrass gathering sites tended to have blue-green hued leaves (Hummel and Lake 2015). Leaf color, color consistency, length, width, pliability, leaf moisture, taper, tensile strength and other factors can all influence the quality from a basketry perspective. Commercial floral industry harvesters have a different but somewhat overlapping set of criteria for harvestable leaves. This apparently includes leaves that are dark green, free of blemishes or brown tips, and up to 76 cm in length (Blatner *et al.* 2004), though another source indicates bright green leaves are preferred and suggests leaves are preferred up to their maximum length, which is reportedly 30 inches, or 76 cm (Schlosser, WE; Roche, CT; Blatner, K; Baumgartner 1992). This latter source also indicates that the center leaves of older plants are preferred because those leaves are younger. Minimum length for commercial harvest may be from fingertip to elbow (Amber Sprinkle, pers. comm.). Another source indicates that deep green, wide, firm blades, longer than 28 inches represent high-quality beargrass for commercial floral industry harvest (Schlosser & Blatner 1997). Brown tips and a yellowish tint to the blade are considered unacceptable (Schlosser & Blatner 1997), based on commercial quality market standards for resale appeal (e.g., use in floral arrangements).

Native Americans have managed beargrass using fire for millennia, and fire is generally considered to increase the quantity and quality of beargrass leaves for basketry (Anderson 2005; Lake 2007). Fire severity can refer to the impact of the fire on soils and vegetation through the consumption and decomposition of organic matter (Keeley 2009). It is correlated with the intensity of the fire (amount of heat and residence time) and with plant and soil dryness at the time of fire, but also depends on factors such as weather, species composition, and soil type (Keeley 2009). Some Native Americans in the southern portion of the Pacific Northwest consider the best quality beargrass collected after moderate intensity fire and in partial shade (e.g., Lake 2007:246). This is consistent with other work that found that low-light environments are associated with poor quality (dark-colored) leaves (Hummel and Lake 2015). In other regions of the Northwest, Native Americans have employed low intensity fires followed by harvest within 1-3 years (Shebitz, Reichard & Dunwiddie 2009). Fire suppression over the last 150 years has increased fuel loads, in some cases increased the severity of fires while reducing their frequency (Reilly *et al.* 2017), and has reduced the abundance and harvest quality of beargrass (Levy 2005; Shebitz *et al.* 2009). There is need for management in contemporary forest contexts to increase the abundance and quality of beargrass populations, but the impacts of fire, canopy conditions and their interactions on beargrass survival, reproduction and leaf quality are poorly understood (Hummel et al. 2012).

In order to evaluate the impact of forest management on beargrass population dynamics, and to explore "crosswalks" between indigenous and non-indigenous management goals and practices, we measured the impact of fire suppression (through fire severity), harvest, soil moisture (as a component of climate change) and light availability (a component of timber thinning and timber harvest) on the population viability (the ability of the population to sustain itself over time) and leaf quality (acceptability to harvesters) of beargrass (*Xerophyllum tenax* Melanthiaceae) in the Cascade Mountains of Oregon using beargrass plots occurring across a range of fire severities. This species and these drivers and response variables were chosen as a sample system that emphasizes key management practices while focusing on a plant of high cultural value. This approach is expected to provide meaningful results for managers as well as for Native Americans who gather or utilize beargrass.

Materials and Methods

Site Selection

To test the effect of fire suppression and other drivers on beargrass vital rates, long-term persistence and leaf qualities, we surveyed 2014 wildfires on Mount Hood National Forest that were at least one acre in size, that had at least 1000 beargrass plants (ramets) that had experienced fire. We selected the first three sites that met these requirements. These sites occur within the Pacific Silver Fir Zone and are each separated by at least two miles (Table 1). All fires were lightening ignitions, put out by a fire crews by digging of a fire line and use of water.

Table 1. Beargrass study sites

Site	Date of wildfire discovery	Size of fire (acres)	Elevation (ft)
Site A	7/16/2014	5	4400
Site B	9/17/2014	2.3	3800
Site C	7/16/2014	30	4000

Plot Selection

Three plots within each site were established using a stratified random approach. Georgia Fredeluces and field assistants surveyed each fire and visually inspected fire severity, canopy openness, soil characteristics, slope, aspect, and beargrass plant density across the entire fire. In order to select plots that would be comparable across sites, we choose to stratify our plot selection by slope and aspect. A southeast aspect and slope between 20 and 45% was chosen because these characteristics were common across sites and would limit variation in the study caused by these variables. At each site, using a Garmin 650 Rhino GPS, we walked the perimeter of regions of the fire with a southeast aspect, and a slope between 20 and 45%. The fine-scale map of our path from the GPS unit was hand drawn on graph paper based on the recorded GPS track and then divided into equally-sized areas using the boxes drawn onto the graph paper. Each section was then numbered, and a random number table was then used to select a plot within the burn. We then used the GPS to navigate to the center of the chosen square and used that point as the plot center for the high-severity plot. Plots were accepted as a high-severity plot if there was at least 30% beargrass cover, at least 100 beargrass plants within a 4 x 4 meter (m) area, at least 80% of the plants had been burned, and there was >75% tree mortality. The unburned sites were then selected by walking from plot center to the closest fire perimeter (usually the fire line dug by the fire crew) and walking 20 paces (45 feet) perpendicular to the fire line. This plot center for the unburned site was selected if it had at least 30% beargrass cover, with a southeast aspect and slope between 20 and 45%. If plots did not meet these requirements, a die was rolled to determine the direction of movement (away from the fire with an 180-degree range of possibilities split into six pie regions) and we walked in the direction rolled until arriving at an adequate site. Low severity burn plots were selected by walking along the same elevation as the high severity burn plot, in the opposite direction of the unburned plot, until reaching a scorched area that had at least 100 beargrass plants in a 4x4 m area, 80% of beargrass plants had leaf scorch and there was <25% tree mortality. The criteria were easy to accommodate at all of our sites.

Plant Measurement Overview

All plants within each plot were tagged and numbered using metal tags and wire or turf stakes. In late July and early August of 2015, 2016 and 2017, demographic measurements were taken on all individuals. Leaf browse by animals or insects was recorded and was uncommon. New plants in 2016 or 2017 were recorded as those that were not present the previous year based on detailed maps and plant tags. Seedlings were plants that emerged and were not within or clones of another plant. These tended to grow more slowly and be smaller at time of emergence than the clonal offspring.

Fire severity metric

In this study, fire severity was determined for both plots and individual plants. In assessing burn severity we referred to the Burned Area Emergency Response (US BAER) soil assessment

(Parsons *et al.* 2010) in combination with identifying burn severity with an approach modified from (Ryan 2002) with categories of unburned, low severity and high severity based on soil and vegetation consumption. Satellite imagery-based assessment of fires, referred to as differenced Normalized Burn Ratio (dNBR), can often provide this information, but this type of data is not available for these fires because these fires are smaller than the minimum size for inclusion in dNBR assessment. We visually inspected severity of burn to soils, understory and overstory and recorded these observations for each plot. At the plant (ramet) level, we created an index of burn severity (Table 2). Additionally, burn depth (height of plant blackened by fire) of each plant was recorded using a measuring tape.

Table 2. Plant burn severity index designed by G. M. Fredeluces

Plant burn severity	Description
0	Unburned – no sign of fire impact on soil or beargrass
0.5	Intermediate between unburned and scorched
1	Scorched – beargrass leaves are singed (white color), but not blackened, and not burned off. Moss brown and dry, but not consumed
1.5	Intermediate between scorch and light burn
2.0	Light burn – beargrass leaves have been burned off, but not all the way to the base of the plant
2.5	Intermediate between light burn and burned
3	Burned – beargrass leaves are burned off and blackened at the bases. The height of burn was measured separately. Moss consumed by fire or was never present.

Plant Size

The best measure of size was determined through a separate allometry substudy. In this separate study, the basal diameter (measured with digital calipers), crown height, crown width, and length of longest leaf (measuring tape) were measured for 30 plants at three locations across a wide size range, that were then harvested at the ground level. Leaves were cleaned and then a random subsample of each plant was used to determine the total leaf area (L-COR LI-3100C Area Meter). The total aboveground biomass was determined by drying the subsample at 80°C for 48 hours in a drying oven (VWR Brand), then weighing on an analytical balance (Ohaus Explorer Pro). Basal diameter (0.89), followed closely by plant crown width (0.87) had the strongest correlations with both total leaf area and plant aboveground biomass. Basal diameter was therefore chosen for subsequent size measurements in this study. Here basal diameter was measured in millimeters (mm) with digital calipers at the plant base, excluding dead leaves.

Reproduction

Sexual reproduction was recorded based on the presence of flowering stalks. The number of seed capsules was counted to determine reproductive output. If inflorescences had not fully formed their seed capsules at the time of census, pedicels were counted in their place. Because of the prevalence of flowering stalk herbivory by deer and elk, and seed herbivory by squirrels and other animals, in cases where flowering stalks were broken off, we used the relationship of flowering stalk basal diameter to seed capsule production to estimate total seed capsule production. The relationship of plant size measurements to capsule production and the average number of seeds per capsule were determined through a series of separate measurements in a separate substudy. In this substudy, we found that the length and the basal diameter of the flowering stalk were most strongly correlated with number of capsules (corr = 0.80 for both). Therefore, for plants that had partially consumed flowering stalks (observed in almost every case of herbivory), the basal diameter of the flowering stalk was used to estimate capsule production using coefficients from the best fit model. Basal diameter of flowering stalks was measured with digital calipers at the point where the flowering stalk emerged from the base of the leaves, or as close to that point as possible. Asexual reproduction (vegetative or clonal reproduction) was determined by counting the number of new ramets occurring each year that were within another ramet.

Mortality

Plants (ramets) were considered dead if they have no live (green) tissue for two consecutive years or if entirely uprooted. Designations of death were reversed if the same ramet had green growth in the following year. This only occurred once. Plants marked as dead in 2017 were not checked again in 2018.

Seed Germination Rate and Seed Bank Study

In order to determine the survival and germination of seeds, and to explore the longevity of the (possible) seed bank, seeds were collected from individuals in two of the study three sites (site C could not be included because plants did not flower in the first year). Seed capsules open when seed is mature in late summer (Vance *et al.* 2001) and mature seed is tan in color (Wick, Evans & Luna. 2008). At sites A and B, one inflorescence on 20 separate clumps (genets) were selected from two different locations outside the fire. Due to low numbers of plants flowering within the surrounding unburned area at Site A, seeds were also collected from plants flowering within the fire (but not within our plots). Care was taken to carry out seed collection at locations separate from the study plots and on plants that were each separated by at least 5 meters. Twenty seeds were collected per individual by shaking mature, beige-colored seed out of dehisced (open) seed capsules. These 20 seeds were separated into two mesh bags for a total of 10 seeds per bag and two bags per plant (400 total seeds). These nylon mesh bags were buried separately at 6 cm depth (Hooftman *et al.* 2015). At each site, seed from unburned areas was buried at a single site that was unburned and at site A, seed from the burned area was buried at a burned location. In years two and three, half of the bags (one from each plant) was dug up and assessed for germination immediately in the field and then again under dissecting microscope. Germination was defined as emergence of the radicle from the seed. For those seeds that did not germinate, seed viability was tested in 2016 (year two) using tetrazolium staining at the Oregon State Seed Lab, and in 2017 (year three) through a germination study based on published procedures for beargrass (Smart & Minore 1977) at the Rae Selling Berry Seed Bank & Plant Conservation Program.

Canopy Openness

Canopy cover refers to the proportion of the forest floor covered by the vertical projection of the tree crowns (Jennings, Brown & Sheil 1999). Canopy closure refers to the proportion of the sky hemisphere obscured by vegetation when viewed from a single point and canopy closure is likely most relevant to light availability understory plant species (Jennings *et al.* 1999). Canopy openness (the inverse of canopy closure) was recorded with a hemispheric camera lens using one picture above each beargrass plant (ramet), as necessary, taken at 0.5 m (Rich 1990). Gap Light Analyzer Software Version 2 was used to analyze results using blue color filter and 110 contrast (Frazer, Canham & Lertzman 1999). All pictures were captured before sunrise, after sundown, or on cloudy days either in 2016 or 2017.

Soil Moisture

Soil moisture was measured at the ramet level using a handheld probe with digital readout (Hydrosense II, Campbell Scientific). This probe integrates the soil moisture measurement over the probe length of 12 cm. Due to the inability to consistently measure soil moisture right at the rosette base because of the presence of roots or rocks, and due the variance in measures of soil moisture within a 10 cm^2 area, we took the average of three measurements equally spaced around each plant in 2016. Measurements were taken twice per field season (late May/early June and late July/early August), with the aim to capture the maximum relative differences in soil moisture experienced by the plants. In 2017, we measured plants at the same two times of year, but only took one measurement per plant due to time and resource constraints. Measurements were not taken in 2015 as we did not have access to a soil moisture probe in that year.

Soil Type

Soil type has been previously published in a Forest Service document and was confirmed to be similar across our sites through on-the-ground assessment with Forest Service personnel (Todd Reinwald/Mount Hood National Forest). Soils were all silty loam. At site A organic horizon was about 3 inches, matted from seasonal snowpack. It also seemed to contain some ash. The A horizon was about 5 inches. Soil in the burned area at this site suggested many fires had burned there. Unburned area around the fire was slightly rockier. The other two sites (B and C) had similar soil types.

Harvest Treatment

In 2016, G. Fredeluces and field assistants completed a harvest experiment on a random subset of leaves across plots and sites. Twenty harvest-quality (>20 cm basal diameter, non-flowering) ramets were randomly selected per plot and harvested to simulate one harvest technique practiced by NW Native American beargrass gatherers. Ten leaves were plucked from the inner-middle portion of the plant. These were the youngest mature leaves, darker in pigmentation than the newest inner leaves, and with a recurved tip (Rentz 2003). The timing of harvest followed recommendation of a cultural practitioner. The number of plants harvested—no more than 20% in a given area—matched one documented practice (Baldy 2013). Twenty control plants that met harvest criteria were also assigned randomly. As much as possible, harvest and control ramets were assigned within separate genets.

Leaf Traits (leaf quality)

In order to include attributes that may be important to weavers, leaf color (hue, value and chroma), length, width, taper and LMA (leaf mass per area) were measured in this study (Table 3). LMA is included as a proxy for strength instead of leaf fracture resistance (tearing, shearing, punching of the leaf) because of potential inaccuracies and challenges associated with measuring leaf mechanical properties (Aranwela, Sanson & Read 1999). We measured LMA by weighing oven-dried leaves and then measuring their leaf area with a leaf area meter (L-COR LI-3100C Area Meter). Leaf mass was determined on an analytical balance (Ohaus Explorer Pro). LMA was then calculated as mass divided by area. The LMA measurements taken in this study are not typical, as they are on leaves that were dried and bleached in the sun for two weeks, stored for one year in a cool, dry place, then oven dried before being weighed. The leaves were also weighed whole (wrapped and held together with a clip that was included in the tare weight), in order to preserve them for future use in basketry. The bleaching and storing procedures were used to approximate Indigenous processing of leaves for basketry. The leaves that were removed in the harvest experiment were the same leaves used for these leaf quality measurements (a subset of three leaves randomly chosen from the 10 leaves harvested on ~20 individual plants per plot). Across nine plots this was 180 plants, and ~540 leaves. Within six hours of harvest, leaf color was determined on the midpoint of each of these leaves using a Munsell color chart. Hue, value and chroma were the aspects of color recorded. Leaf length and width at three points was also recorded (midpoint, halfway between leaf midpoint and base, and halfway between the leaf midpoint and apex). Taper was calculated as the ratio of the more anterior leaf width measurement to the more posterior measure.

Table 3. Leaf traits measured in this study

Leaf characteristic	**Desired state**	**Measurement protocol**	**Type of data**
Color	Middle green-yellow hue (5GY) and leaf hue consistency at a site may be preferred	Midpoint of leaf measured with Munsell color chart. Hue, value and chroma recorded.	Continuous and ordinal, along multiple axes
Length	Generally, longer	Distance from base of the leaf to the end of leaf including only live (green) tissue	Continuous (cm)
Width	Generally narrower, but preference varies	The width at midpoint	Continuous (mm)

Taper (width constancy)	Depends on weaving style	Ratio of width half way between leaf midpoint and base and half way between midpoint and apex	Continuous (no unit)
Leaf mass area (LMA)	Stronger leaves preferred for basketry, and LMA likely correlates positively with strength	Total leaf area divided by dry leaf mass	Continuous (grams/m^2)

Access

The quality of a site for harvest depends partially on the accessibility of the site. Access depends on many factors including physical barriers or impediments to access, as well as policies such as permitting. Wildfire and road closures, the financial cost of driving long distances, and knowledge of gathering sites will also influence access. Gathering access and efficiency are also influenced by the allowance of harvesting at desired time of year, distance from road to gathering site, slope at the site, and topographic complexity (more surface and ladder fuels hinder mobility) (Hummel & Lake 2015; Dobkins *et al.* 2016). Plant density could also influence decision to harvest based on harvest effort. Although access was not measured for these specific sites, because this part of the study is intended to provide generalizable ecological information, it can be considered central to discussion of stakeholder needs.

Data Analysis

The influence of measured variables on plant vital rates (growth, survival and reproduction) were determined by building general and generalized linear mixed models (GLM and GLMM) in r (Fournier *et al.* 2012; Bates *et al.* 2015; R Core Team 2016). Based on our study design, we used plot nested within site as a random factor. For Gaussian family models (growth models), variance covariates were selected for each year with AIC. For 2015 to 2016, the power variance covariance was selected. For 2016-2017, the variance covariance varied by burn severity category (high severity, low severity and unburned). For all models, best models were selected using AIC, starting with the full model including all drivers and their interactions with plant size, and then sequentially removing least significant terms (interactions first, then quadratic, then main effects) until arriving at the model with the lowest AIC (Akaike 1973; Zuur *et al.* 2009). Terms were replaced (whether significant or not) if their removal increased the AIC value. For Gaussian family models, model validation included graphing residuals to confirm normal distributions and homoscedasticity. All models were checked for collinearity. The only instance of collinearity was the structural collinearity between early soil moisture and the early soil moisture by plant size interaction occurred for the growth from 2015-2016 model. We report on vital rates by year-since-fire except in the case of capsule production and number of clones produced, where we combined the 2016 and 2017 data. Survival and flowering are reported for 2015, but clonal reproduction is not included in 2015 as we could not distinguish between clones that emerged the year we monitored and clones that had emerged in years past. Though beargrass is monocarpic, survival models do not include plants that died due to flowering. This is captured in our flowering models. Long-term growth rates for each population across fire severities were calculated for the 2015-16 and 2016-17 growing seasons by combining vital rate models into an Integral Projection Model (IPM) (Easterling, Ellner & Dixon 2000; Ellner & Rees 2006). Life Table Response Experiments (LTREs) were then used to identify which demographic factors explained observed differences in population growth across fire severity categories (Caswell 2000). Leaf quality data (leaf traits) were compared across burn severity classes graphically and with ANOVA. The influence of fire severity and other factors on leaf qualities were explored with generalized linear mixed models, with best models selected using AIC (Zuur *et al.* 2009). For the leaf quality analysis, we used plant burn severity at the plant level, following the index above, rather than data at the plot level.

Results and Discussion

Seed Germination Rate and Seed Bank Study

Of the seeds buried in late summer of 2015 and uncovered in late summer of 2016, an average of 27.2% of the seeds per bag germinated (stdev of 27.8%, n=27 bags, each with ~10 seeds each from a separate plant). Germination rate of a given bag in the field ranged from 0-71%. Viability analysis in 2016 through tetrazolium staining indicated that only an additional 9.2% of the remaining, ungerminated seeds were viable. In late summer 2017, the remaining seed bags were dug up and had an average germination rate of 41.7% per bag (stdev of 28.4%, n=21 bags, each with ~10 seeds each from a separate plant) over two years. Germination rate of a given bag in the field in 2017 ranged from 0-100%. Some of the seeds clearly germinated in year two (green shoots still present), indicating that beargrass has a seed bank and that seeds can persist for at least 21 months underground before germinating. Seeds that did not germinate in the field by 2017, also did not germinate in the lab. For both years, it is possible that warm seed storage temperatures lowered viability and germination (for example, the seeds may have gone back into dormancy by late summer or after experiencing warm temperatures when they were taken from the mountains down to Portland, OR where they were kept for several weeks before germination trials could be initiated).

Survival

Survival generally decreased with increased fire severity and varied with time since fire (Figure 1). Survival also decreased as canopy openness increased. Fire severity and canopy openness were not collinear in our models, but are associated factors that may be better disentangled through additional statistical methods such as Structural Equation Models (Grace *et al.* 2012) that can distinguish between direct and indirect effects of drivers on plant vital rates. Although the effect was smaller, harvest also decreased survival rate in 2017. The effect of plant size on survival varied with time since fire, with primarily larger plants dying one year post-fire and primarily smaller plants (seedlings) dying three years post-fire. This result may be somewhat biased by our inability to detect death of small plants one year post-fire because small plants may have been burned up entirely and therefore not detectable in our census one year following fire.

The high rate of seedling mortality three years post-fire is mostly a consequence of the high recruitment of seedlings two years post-fire and what we assume are naturally low rates of seedling survival for this species in the subalpine zone. Very few seedlings were found in the high severity burn plots, suggesting this fire severity does not support recruitment of seedlings in the three years following fire. This is contrary to the results of Shebitz *et al.* (2009) who, working at a low elevation site on the Olympic Peninsula found that seedling established was increased in the high severity burn areas with exposed mineral soil compared to reference, unburned, plots. Holding other drivers in the model constant, early season soil moisture and late season soil moisture and did not have an effect on plant survival.

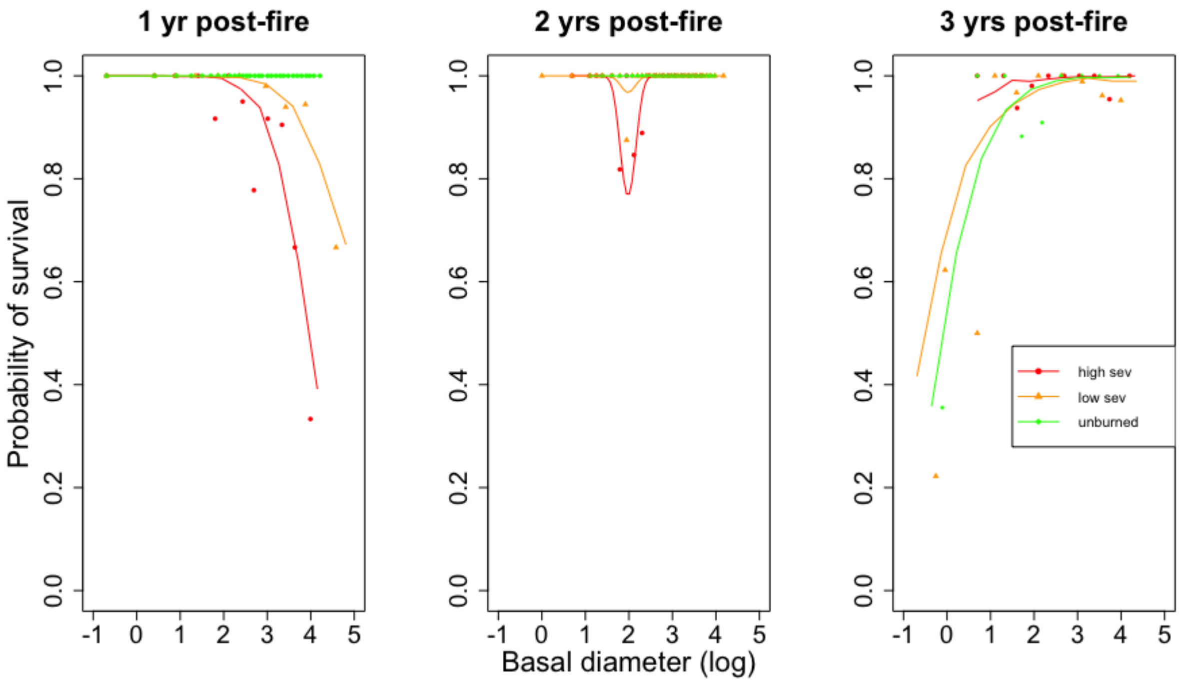

Figure 1. Probability of survival of beargrass plants across fire severity categories one, two and three years post-fire. Points represent the average value for a number of plants within a size interval.

Growth

Plant growth increased with fire severity and decreased with plant size (Figure 2). Increases in plant growth with fire may be a result of increased nutrient availability following fire (Boerner 1982), or the increased light availability that accompanied fire. The decrease in plant growth with size may be a result of larger plants allocating resources to reproduction rather than growth, a natural decrease in growth rate with age, or a result of shrinkage that may occur with the preparation to reproduce. The effect of soil moisture early in the growing season on individual plant growth depended on plant size. Smaller plants had higher growth rates under higher soil moisture conditions, while larger plants had no change or even a decrease in growth rate under higher early season soil moisture conditions (Figure 3). Larger plants may be less sensitive to increases in soil moisture because they already have older, more established root systems and mycorrhizal associations. Holding other drivers in the model constant, canopy openness, late season soil moisture and harvest did not have an effect on plant growth.

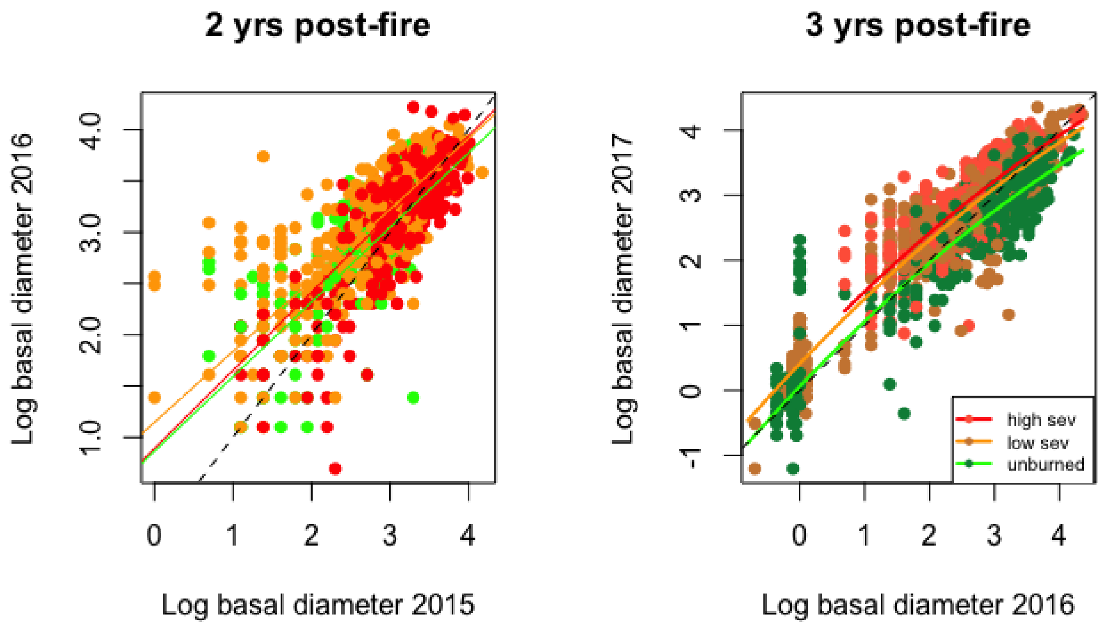

Figure 2. Growth of individual beargrass plants across two different years of growth (two and three years post-fire). The dashed black line is the identity line, or line of zero growth for an individual.

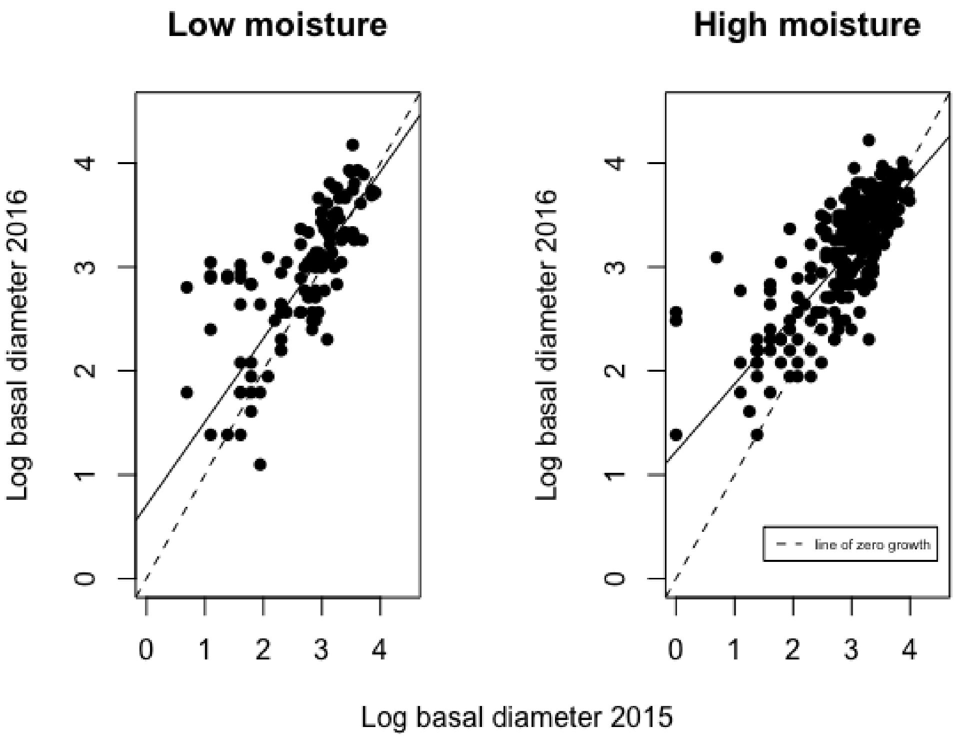

Figure 3. Growth of individual beargrass plants two years post-fire that experienced low and high soil moisture conditions early in the growing season. The dashed black line is the identity line, or line of zero growth for an individual.

Sexual Reproduction

Sites A and B mass flowered in 2015, while Site C (located a bit further from the other two sites) mass flowered in 2017. We are unsure of the cause of the mass-flowering events. The probability of flowering increased with increased fire severity, canopy openness and plant size. The effects of fire severity on flowering occurred in the best model one and two years post-fire, but not three years post-fire, where canopy openness best predicted flowering (Figure 4.). This likely suggests that plant flowering stimulated by fire (perhaps by nutrient inputs or other triggers) lasted for a limited time period (in our case we observed this to be up to two years post-fire). Light availability (as measured here through canopy openness) is known to be important to beargrass flowering. Recent work on the Olympic Peninsula in Washington State found that a minimum of 30 % photosynthetically active radiation (PAR, which was about 50% canopy openness for their study) was necessary for beargrass plants to flower (Peter, Harrington & Thompson 2017). Across the plant size range used in our model (>8 mm basal diameter, which was the smallest plant that flowered in our study), the probability of flowering increased with plant size. Holding other drivers in the model constant, early season soil moisture, late season soil moisture and harvest did not have an effect on probability of flowering.

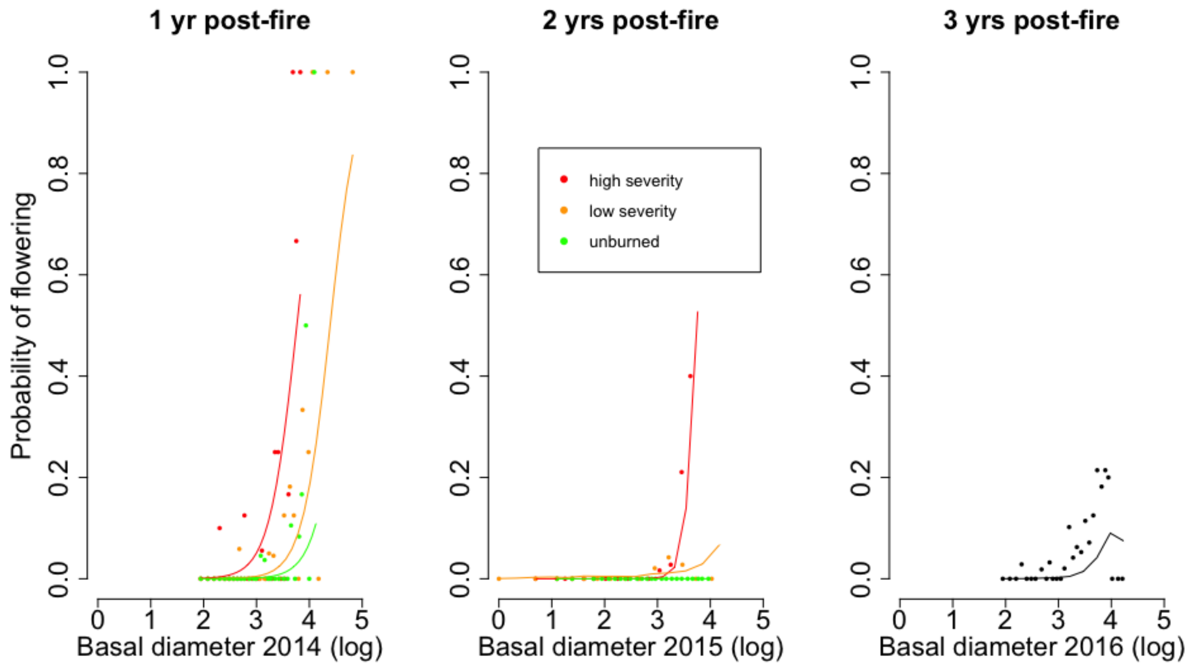

Figure 4. The probability of flowering by fire severity one, two and three years post-fire.

Number of Seed Capsules

The number of seed capsules produced by a flowering plant increased with plant size and with fire severity. Both may be a response to greater nutrient availability, which may have allowed plants to make a larger investment into reproductive output. Holding other drivers in the model constant, early season soil moisture, late season soil moisture, canopy openness and harvest did not have an effect on the number of seed capsules produced.

Vegetative Reproduction

The probability of vegetative or clonal reproduction increased with fire severity, plant size, canopy openness, flowering, late season soil moisture and harvest (Figure 5). The effect of fire severity and flowering depended upon plant size in both 2016 and 2017, while the effect of canopy openness depending upon plant size in 2016, but not in 2017. In 2016, as canopy openness (light) increased, the probability of vegetative reproduction increased for small, but not large plants (Figure 6). This may indicate that more open canopy conditions stimulate vegetative reproduction in smaller plants through a different mechanism than fire, with fire potentially having a stronger impact on larger plants. The impact of harvest (only assessed in 2017) did not depend on plant size. Holding other drivers in the model constant, early season soil moisture did not have an effect on the probability of vegetative reproduction.

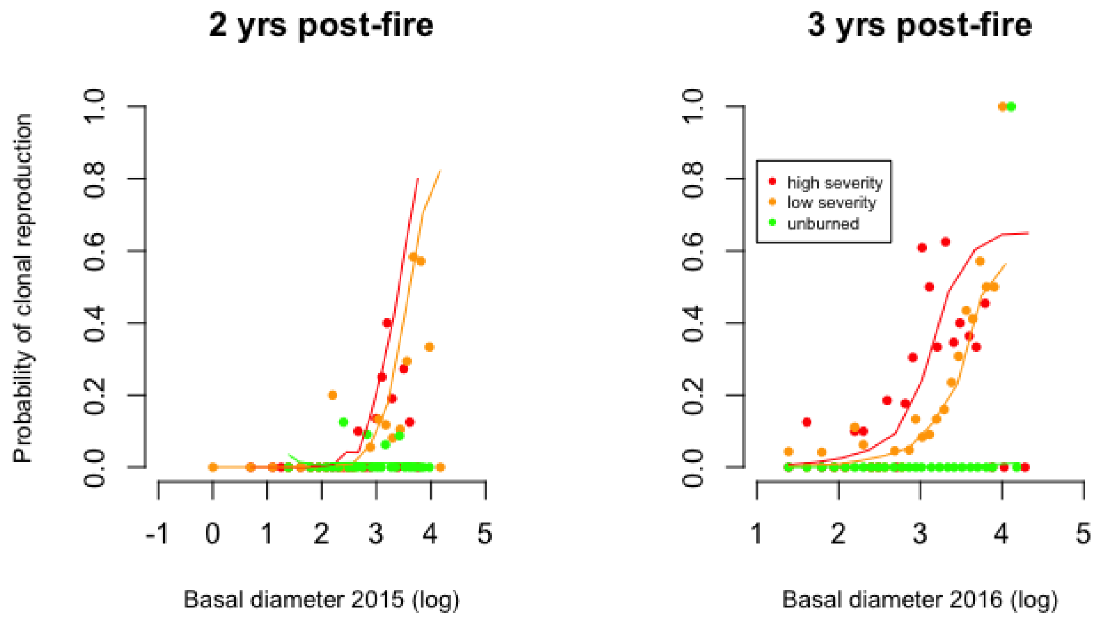

Figure 5. Probability of clonal reproduction two and three years post-fire by burn severity.

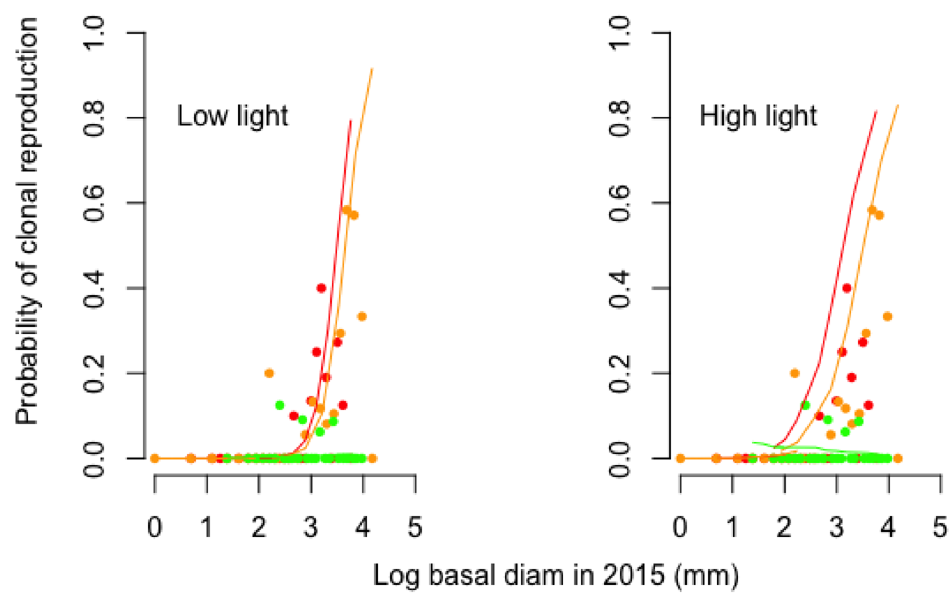

Figure 6. Increased light (canopy openness) increased the probability of vegetative reproduction in 2016 in smaller, but not larger plants.

Number of Clones

The number of clones produced by a plant that vegetatively reproduced increased with plant size, likely due to increased resource availability in larger plants. The effect of soil moisture on number of clones depended on plant size. For smaller plants, decreased late season soil moisture increased the number of clones, while for larger plants there was little impact of soil moisture. This may indicate that smaller plants are more sensitive to the effects of moisture than larger plants that likely have more access to water through larger and older root systems. This provides some indication that vegetative reproduction in these smaller plants could be a stress response to low moisture conditions. Holding other drivers in the model constant, burn severity, canopy openness early season soil moisture and harvest did not have an effect on the number of clones produced.

Long-term Population Growth Rates

Long-term population growth rates (lambda), meaning the projected population growth rate if the given conditions in the model were to remain the same, were highest for plant populations that experienced fire. In most years, low-severity fire led to the highest population growth rate. In 2015, low-severity fire led to the highest population growth rate, and the LTRE analysis indicated that this was driven by higher survival, growth and vegetative reproduction compared to the high-severity populations (Figure 7). In 2016, high-severity fire led to the highest population growth rate, and the LTRE analysis indicated that this was driven by higher levels of sexual reproduction of the largest individuals in those populations compared to low-severity populations (Figure 8). In 2017, low-severity fire led to the highest population growth rate, and the LTRE analysis indicated that this was driven by higher levels of growth and reproduction in the low-severity burn populations compared to unburned populations (Figure 9). These long-term projections are useful in understanding how populations are performing across a burn severity gradient with time since fire. However, it is not realistic to assume that conditions in any given year since fire would remain constant over time. Therefore, the next steps in this project will be to use Monte Carlo Methods to simulate and compare two fire regimes: infrequent, high severity fire that is becoming more common in some regions with fire suppression, and frequent low-severity fire, which is the management approach used over millennia by Native Americans to manage particular subalpine areas. This will give us a better idea of the long-term impacts of fire suppression on this plant of cultural and ecological significance.

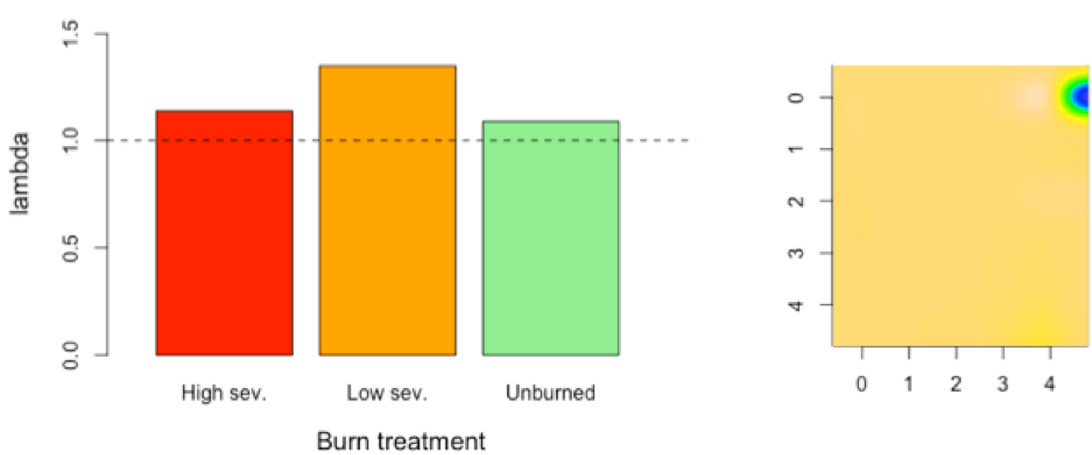

Figure 7. Left side: Long-term population growth rate (lambda) of populations experiencing high severity, low severity and no fire in the conditions one year post-fire. Right side: Life Table Response Experiment result for a comparison of low severity and high severity populations. The axes represent plant size on a log-scale and colors (dark to light) indicate increasing importance of a transition from a plant of a given size on the x-axis to a plant of a given size on the y-axis.

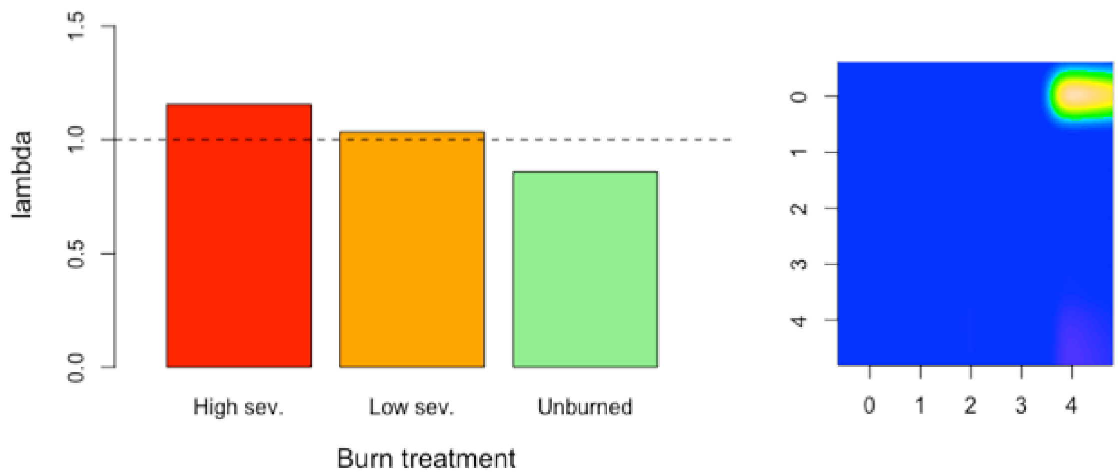

Figure 8. Left side: Long-term population growth rate (lambda) of populations experiencing high severity, low severity and no fire in the conditions two years post-fire. Right side: Life Table Response Experiment result for a comparison of low severity and high severity populations.

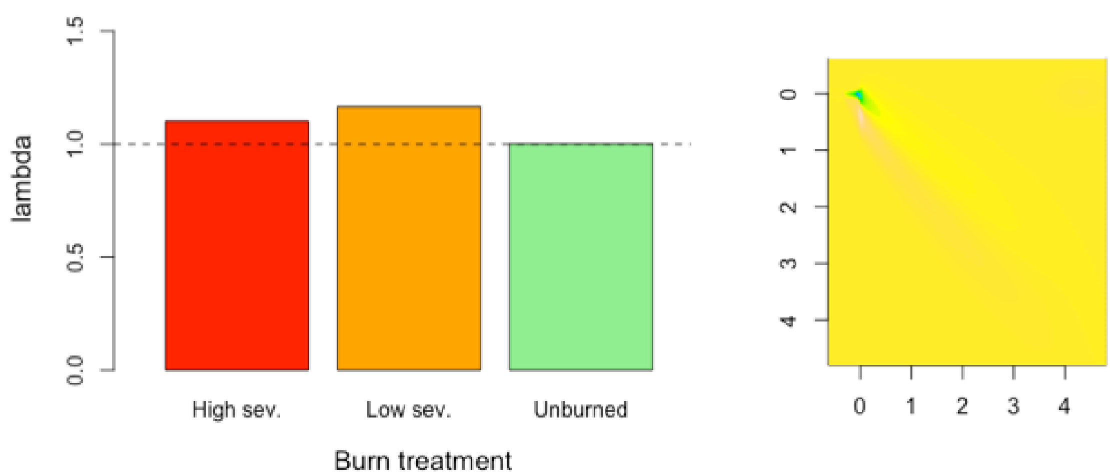

Figure 9. Left side: Long-term population growth rate (lambda) of populations experiencing high severity, low severity and no fire in the conditions three years post-fire. Right side: Life Table Response Experiment result for a comparison of low severity and unburned populations.

Leaf Traits

Plants in the low and high severity burn populations appear graphically to have shorter and wider leaves than plants in the unburned plots (Figs 10 and 11), though these differences are not statistically significant. These leaves were from the second innermost whorl of the plant and were gathered for the harvest experiment described in the methods section above. Leaf mass per area, or LMA (similar to leaf thickness and a used here as a proxy for leaf strength), did not vary with burn severity in our mixed model analysis at the plant level, but plants in the low-severity burn populations (plots) did have a higher LMA than leaves in the high-severity ($p < 0.0001$) and unburned populations ($p< 0.0001$) based the ANOVA analysis with post hoc Tukey HSD comparisons (Fig. 12). The reason for the difference is likely the inclusion of the random factor in the regression model, indicating that the difference by ANOVA could have been driven by site-based differences. Leaf taper was more variable in burned populations compared to unburned populations (Fig. 13). The best model for leaf length found that it increased with plant size and with canopy openness. The best model for leaf width found that it decreased with late summer soil moisture and increased with canopy openness. The best model for leaf taper and LMA were not described by any of the factors measured in this study. Leaf hue was fairly consistent across burn severities (all green-yellow), perhaps decreasing slightly (becoming less green) with fire (Figure 14). Leaf value (darkness) increased with fire. Leaf chroma (color saturation or intensity) did not seem to vary with burn treatment, but showed a greater spread in values in the low-severity burn populations. Certain leaf colors were more common in high-severity populations, and other leaf colors were more common in low-severity and unburned populations. Assuming a general preference for longer, narrower, stronger leaves with more consistent leaf hue of the value 5GY, we can say that low-severity fire may be associated with the strongest leaves, at least at certain locations, while high severity fire may provide a wider range of leaf taper, but potentially lead to more yellow-tinged leaves.

Somewhat contrasting with our results, other studies have shown that burning decreases the leaf thickness (thickness of fibers below the hypodermal layer) (Rentz 2003). This same study observed, contrary to our graphical observation, that leaves from the burned plants were visually thinner than those from unburned areas. Another study on the Olympic Peninsula found that leaf length and specific leaf area (SLA, the inverse of LMA) were higher in the presence of overstory trees (Peter *et al.* 2017). Contrary to that study, our mixed model analysis found that leaf length increased with canopy openness and that LMA was not affected by canopy openness. The same study also measured leaf color, which they found differed with the presence or absence of overstory trees. In agreement with their study, we found leaves in areas that experienced fire (which correlated somewhat with more open canopy conditions) were less green (more yellow), and lighter (higher color value).

Differences in results across studies may relate to differences in study design, in statistical approach, or could indicate that beargrass shows varying responses to environmental drivers dependent on factors that vary across the three study regions (northern California, northern Oregon, southern Washington) such as elevation, climate, historic Native American-set fire regimes, natural fire regimes, beargrass genetics, plant association, bedrock, or other factors.

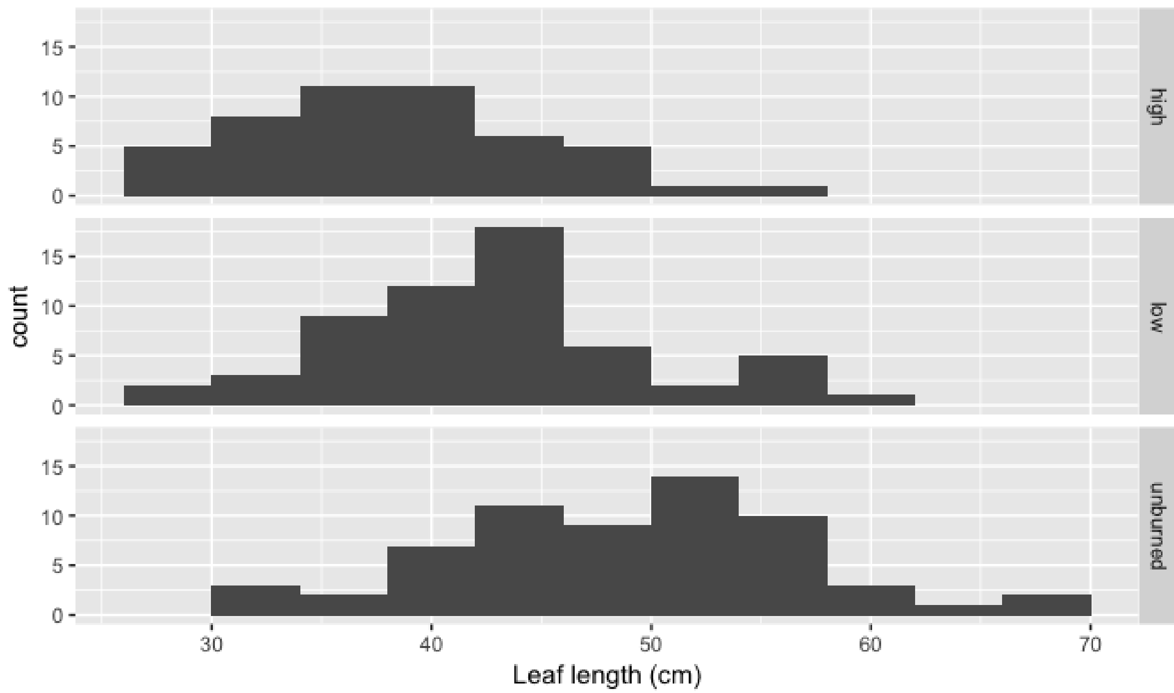

Figure 10. Histograms of leaf length of a subset of leaves gathered across high-severity burn, low-severity burn and unburned populations.

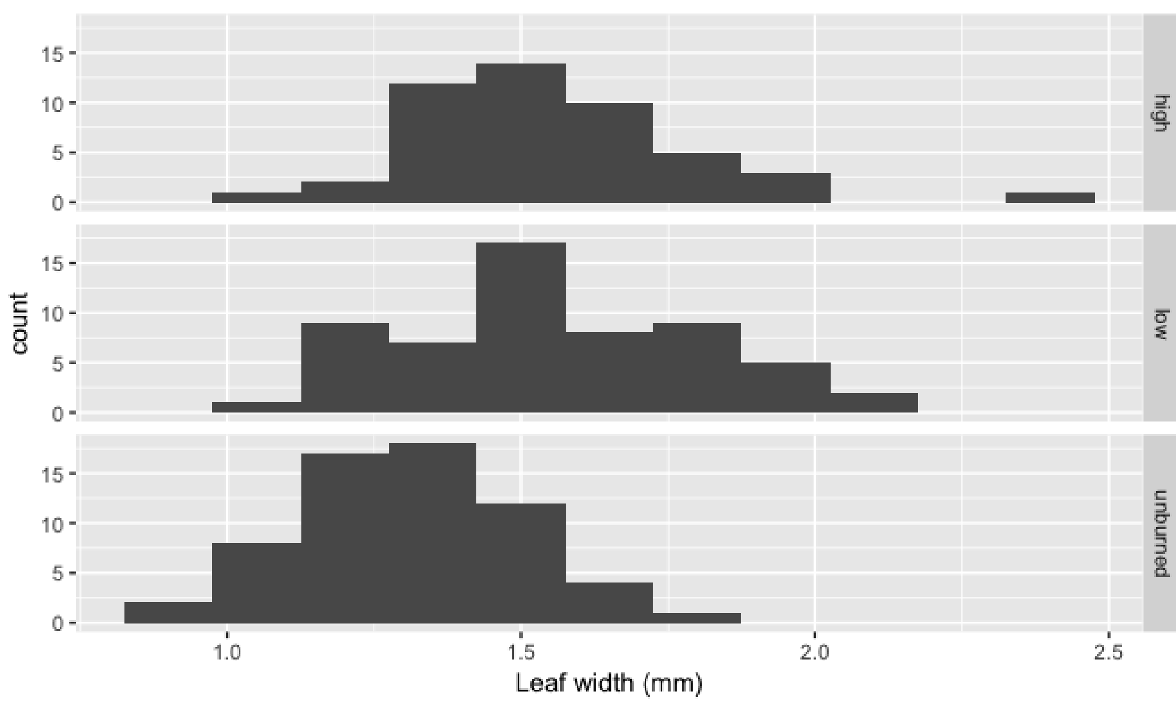

Figure 11. Histograms of leaf width of a subset of leaves gathered across high-severity burn, low-severity burn and unburned populations.

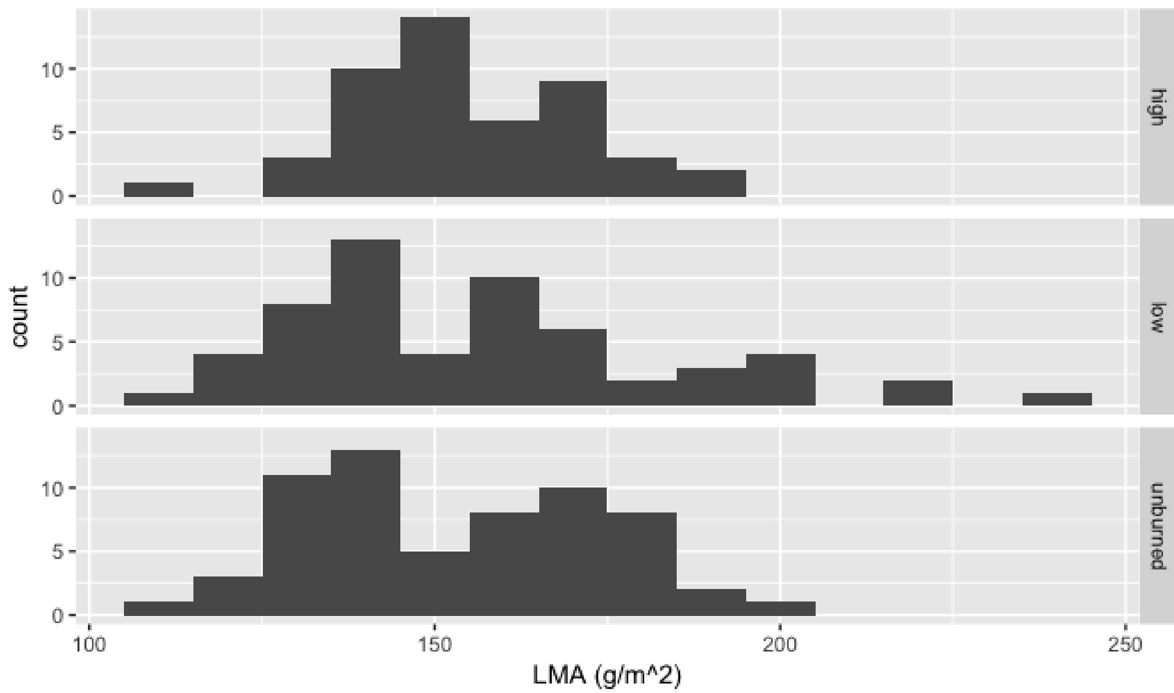

Figure 12. Histograms of leaf mass per area (LMA) of a subset of leaves gathered across high-severity burn, low-severity burn and unburned populations.

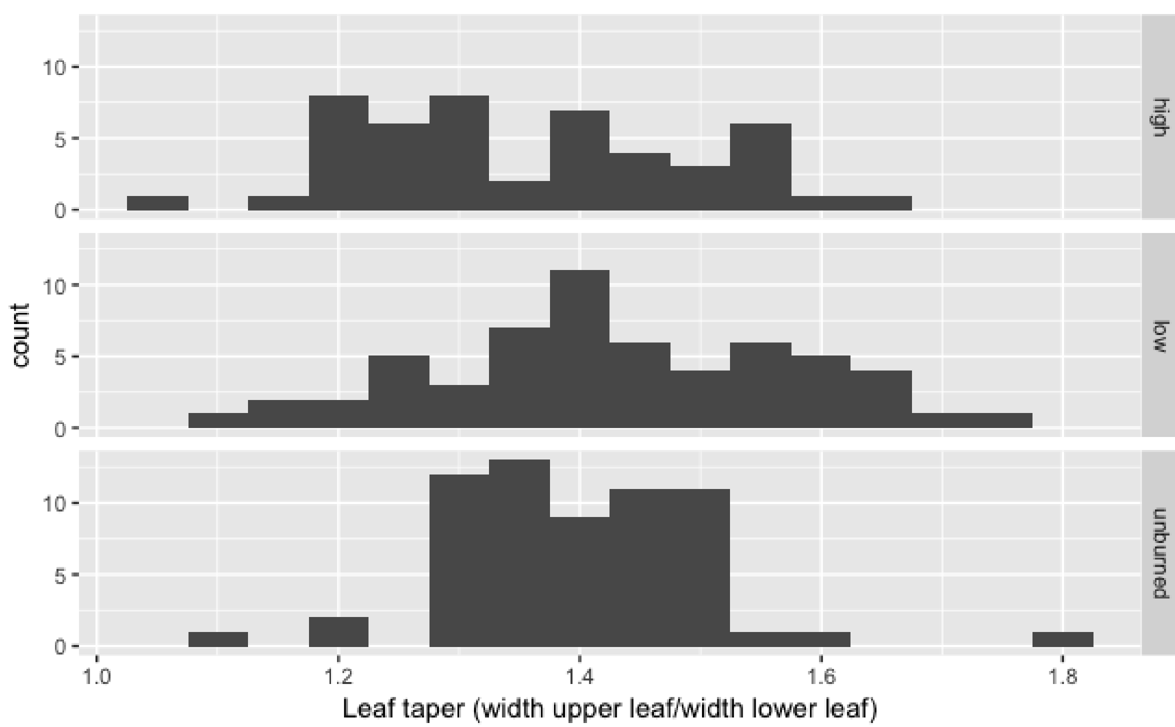

Figure 13. Histograms of leaf taper of a subset of leaves gathered across high-severity burn, low-severity burn and unburned populations.

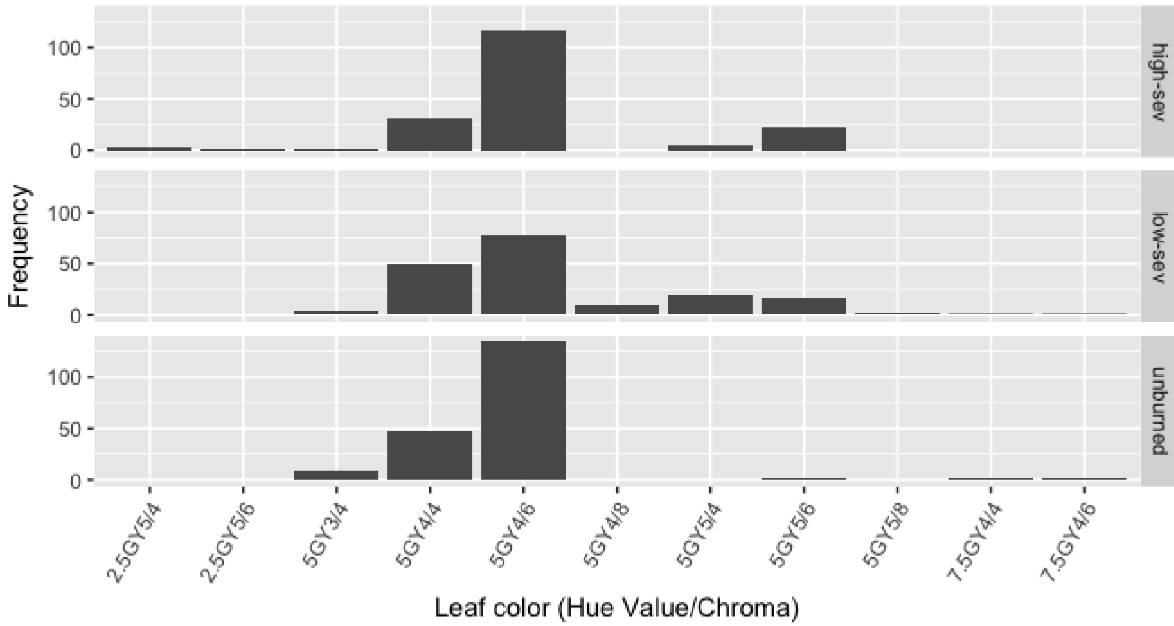

Figure 14. Frequency of leaf colors by burn severity.

Conclusions (Key Findings) and Implications for Management/Policy and Future Research

Plants that experienced low-severity fire generally had the highest plant population growth rates. However, the long-term consequences of changes to fire severity and frequency for beargrass populations in subalpine areas of the Cascade Range will be better understood after we complete the next phase of analysis. This next phase will involve using Monte Carlo Methods to simulate and compare infrequent high-severity fire regimes, which are a proxy for effects of fire suppression, with frequent low-severity fire regimes, which are a proxy for Native American fire management. We will also need to incorporate seed bank dynamics into our long-term population growth models. Indigenous harvest, increased light availability, and increased soil moisture all had a positive impact on long-term population growth rate. While indigenous harvest slightly decreased plant survival, it also increased plant vegetative reproduction and the overall effect of harvest on long-term population growth was positive. This indicates that indigenous harvest likely supports higher population growth rates of beargrass in the long-term. While the impacts of commercial harvest, which are more intensive, were not directly measured in this study, practitioner observations and extrapolations of our data suggest commercial harvest is not sustainable. Whether sustainable or not, it decreases access to quality plants for some basket weavers. Low-severity fire, high severity fire, timber thinning and indigenous harvest of beargrass can all be expected to increase the long-term population growth rate of beargrass. Reductions in soil moisture with climate change are expected to decrease beargrass long-term population growth rates. The leaf qualities measured in this study and desired by weavers may not have been impacted or enhanced by fire in the way we predicted. We are continuing to explore and interpret this component of the study with the help of cultural practitioners. Leaf quality preferences vary by weaving style, tribal affiliation, personal preference and other factors. The best way to support access of Native Americans to beargrass plants of high quality would be to support and facilitate the care-taking rights and relationships of Tribal Nations to places where beargrass occurs, and to support the co-management or tribal management of portions of public lands.

Recommendations for the management of beargrass populations subalpine areas of the central Cascades:

- Apply low-severity prescribed burns, as possible, in key beargrass gathering areas that lead to <50% tree mortality

- Thin timber in key beargrass gathering areas to increase canopy openness

- Prioritize conservation efforts to areas less likely to be impacted by drought or reductions in soil moisture with climate change

- Limit or eliminate commercial harvest of beargrass, particularly at locations utilized or important to Native Americans

- Support and facilitate tribal caretaking and management (or co-management) of subalpine areas on public lands of interest for beargrass harvest (such as through Memorandums of Understanding, MOUs, Cultural Special Interest Areas, etc.)

- Hire a tribal liaison to support the communication, trust-building and co-management process for the care of beargrass and other culturally-significant plants on public lands

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Appendix A: Contact Information for Key Project Personnel

Georgia M. Fredeluces
Student Investigator/PI
Department of Botany, University of Hawai‘i at Mānoa
St. John 101
3190 Maile Way
Honolulu, HI
96822
georgia.hart@gmail.com

Dr. Tamara B. Ticktin
Academic adviser/PI
Department of Botany, University of Hawai‘i at Mānoa
St. John 101
3190 Maile Way
Honolulu, HI
96822
ph: (808) 956-3928
ticktin@hawaii.edu

Appendix B: List of Completed/Planned Scientific/Technical Publications/Science Delivery Products:

1. Articles in peer-reviewed journals – two planned for submission in 2018
2. Technical reports - none planned
3. Text books or book chapters – none planned
4. Graduate dissertation – planned for spring 2019
5. Conference or symposium proceedings scientifically recognized and referenced – none planned
6. Conference or symposium abstracts
    a. Ecological Society of America, Oral presentation, August 9th, 2017, Portland, OR

Abstract #66059

Georgia Hart and Tamara Ticktin
Department of Botany
University of Hawai‘i at Mānoa

Title: Multiple and interactive effects influence vital rates and long-term persistence of a culturally significant fire-adapted forest herb in the Pacific Northwest

Background/Question/Methods
In the context of rapid global change, it is essential we understand how environmental drivers are impacting plant population dynamics, yet few demographic studies evaluate multiple drivers or explore interactions. This study tests the impact of fire, soil moisture, canopy cover and their interactions, on vital rates, leaf qualities and population dynamics of beargrass (*Xerophyllum tenax* Melanthiaceae), a forest herb in the Pacific Northwest used in basket making by tribal members and traditionally managed through fire. Here we ask 1.) How do fire and abiotic factors influence plant vital rates and leaf qualities?, 2.) What are the long-term population consequences of more-frequent low-severity versus less-frequent high severity fire?, and 3.) How do canopy cover and soil moisture interact to influence these long-term effects? We censused >1000 plants across burn severities in 2015 and 2016 at three high elevation sites in north central Oregon. Field data were used to parameterize regression models of vital rates and covariate predictors. These were then used to build Integral Projection Models to explore the influence of fire regimes and abiotic factors on beargrass vital rates and long-term persistence. Leaf qualities were measured on a subset of plants across plots in 2016.

Results/Conclusions
Plant growth, survival and sexual reproduction depended upon plant size and burn severity. Capsule production increased with soil moisture. Asexual reproduction increased with flowering in the previous year, and depended upon the interaction of size with burn severity and canopy openness. Long-term persistence of beargrass population was highest under low severity fire, moderated by covariates. Leaf qualities relevant to basket making depended upon severity fire, again moderated by covariates. This study demonstrates the importance of considering multiple effects and interactions in order to disentangle the impacts of management and abiotic

drivers on plant population dynamics. It also highlights the importance of exploring potential trade-offs between management for plant persistence and management for plant qualities necessary for cultural or economic use by stakeholder groups.

   b. Society for Economic Botany/Ethnobiology Society Meeting, Madison, WI – planned attendance June 2018
   c. SESNYC Symposium, Annapolis, MD – planned attendance June 2018

7. Posters - none planned
8. Workshop materials and outcome reports - none planned
9. Field demonstration/tour summaries - none planned
10. Website development - none planned
11. Presentations/webinars/other outreach/science delivery materials – webinar, "Fire Management of American Indian Basket Weaving Plants in the Pacific Northwest" was delivered to over 75 people at 10 AM PST on January 25th, 2018 through the Joint Fire Science Pacific Northwest Region. This was presented along with GRIN recipient Tony Marks-Block.

Appendix C: Metadata

The project includes submission of three .csv files and one metadata document. These are all archived at the Forest Service Research Data Archive as indicated below. The three data files cover plant 1.) demography measurements ("GF_TT_2018_XETE_demography.csv"), 2.) LMA measurements ("GF_TT_2018_XETE_LMA.csv"), and 3.) other leaf attributes ("GF_TT_2018_XETE_leafattributes.csv").

Fredeluces, Georgia M.; Ticktin, Tamara B. (TO BE PUBLISHED 12/31/2019). Demographic and leaf attribute data for beargrass (Xerophyllum tenax Melanthiaceae) from Mount Hood National Forest, Oregon. Fort Collins, CO: Forest Service Research Data Archive. https://doi.org/10.2737/RDS

Fredeluces, Georgia M.; Ticktin, Tamara B. (TO BE PUBLISHED 12/31/2020). Demographic and leaf attribute data for beargrass (Xerophyllum tenax Melanthiaceae) from Mount Hood National Forest, Oregon. 2nd edition. Fort Collins, CO: Forest Service Research Data Archive. https://doi.org/10.2737/RDS